Cybermedicine Tools for Communication and Learning

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The medical domain provides excellent opportunities for communication and teaching of healthcare issues using computer graphics, visualization techniques, and virtual environments. Possible applications include anatomical educational tools; patient education; diagnostic aids; virtual autopsies; planning and guidance aids; skills training; and computer augmented reality. Both clinicians and patients can benefit from the appropriate use of tools that make use of these technologies. This paper provides an overview of the state-of-the-art technologies in this exciting field, including detailed examples from our research. The term cybermedicine is discussed and issues for effective cybermedicine are highlighted.

INTRODUCTION

The term *cyber* is often prefixed to any entity that is undergoing radical changes due to the use of high-tech computers to automate systems. A classic example from science fiction is the 'Cyberman' from the BBC Doctor Who series, where the human body is completely replaced with mechanical parts. This is an extreme possibility for cybermedicine! Today the term *cybermedicine* is typically applied to a range of medical applications that make use of virtual environments and computer graphics technologies. Examples include anatomical educational tools; patient education; diagnostic aids; virtual autopsies; planning and guidance aids; skills training; and computer augmented reality.

Cybermedicine (and telemedicine and e-Health) is also used to refer to the use of the internet for medical related applications. This is a fast growing area with massive consumer demand. A vast amount of information can easily be obtained from hundreds of millions of web sites offering medical information for physicians, patients, or both. There are even web sites that offer consultation services and others that sell medical products. This all leads to the need for research and evaluation into how the internet is exploited for effective consumer health education, patient self support, professional medical education and research, the quality of medical information found, the impact of the internet on the patient-physician relationship and quality of health care, and the use of global networking for evidence based medicine.[1] There are also many legal and ethical issues that must be considered.[2,3] These issues will not be discussed here, however. Instead, this paper focuses on the technical developments related to the use of cybermedicine tools. We will review what has already been achieved, including on the World Wide Web, providing recent examples from our research and look ahead to future developments.

CYBERMEDICINE TOOLS

Three detailed application areas are presented below to illustrate the potential benefits of cybermedicine tools.

Anatomy Education

The teaching of human anatomy makes use of many resources. Comprehensive and detailed text books are available, such as the classic Gray's Anatomy of the Human Body.[4] Problem-based learning scenarios, prosections (pre-dissected specimens), and anatomy models are also commonly used. Performing a dissection of a human cadaver, however, has traditionally been considered as the optimum method for students to gain an excellent spatial understanding that is difficult to glean from a text book alone.

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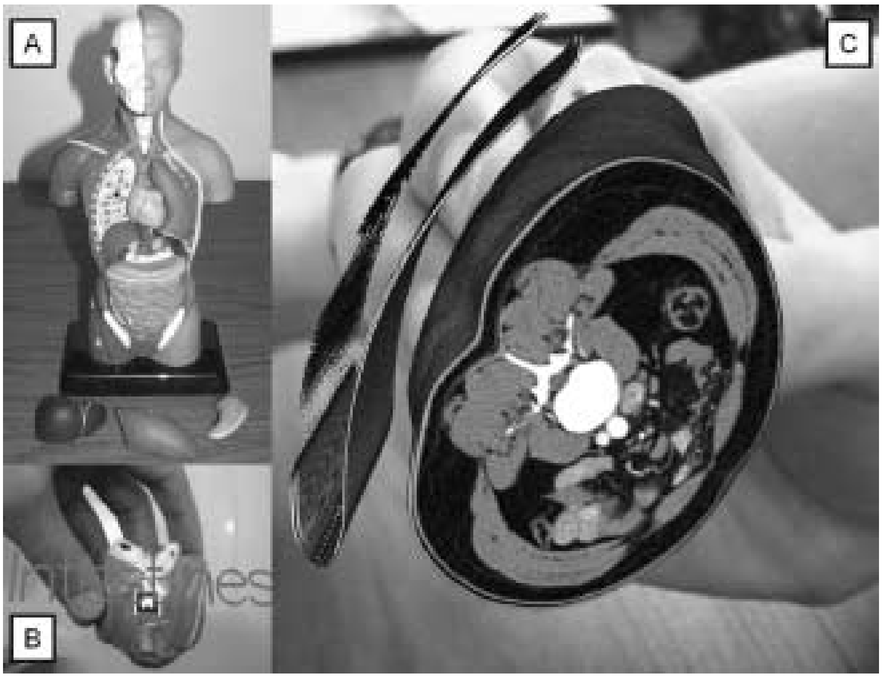

Figure 1. A) Plastic model is the interface device. B) Model part is tracked by a video camera. C) Volume rendering of anatomy is overlaid onto the real time video stream.

Yet dissection has become less common today due to financial and ethical reasons, and some medical schools have taken the decision not to use cadavers in the teaching of anatomy in its undergraduate curriculum. A potential substitute for dissection is to make use of cybermedicine tools to allow the exploration of three dimensional (3D) anatomies. Randomized control studies have recently been published that show the effectiveness of this approach.[5]

Direct volume rendering is a popular technique used to represent and analyse volume data (such as a CT or MRI medical scan) that allows the user to see the internal structure and topology of the volume data.[6] The Visible Human Project[7] has provided a catalyst for the use of high resolution volume rendered medical data for anatomy teaching, for example.[8] Web-based anatomy teaching tools have been developed based on this data set.[9]

At Bangor, we are currently developing a mixed reality anatomy teaching tool.[10] A novel interactive environment allows a student to use a plastic model of an organ to manipulate the position and orientation of a volume rendering of the anatomy (instead of using a keyboard and mouse) (*Figure 1*). The volume rendering of the whole data set or just the organ of interest is overlaid onto the video stream being displayed by the computer. The volume rendering can also be clipped relative to an arbitrary plane to reveal data from its interior, using a second prop such as a plastic rule as the clipping device. We are extending these ideas to include an anatomy segmentation tool based on 3D Colouring software using a classification algorithm from Tzeng.[11] The students can then view the anatomy models in 3D using a stereoscopic display, and even obtain a physical model using rapid prototyping and solid imaging printers.

Procedures Training

Virtual environments are a particular class of cybermedicine tools that have proven effective for training a variety of medical procedures, and there are several commercial products available today.[12] Most solutions use special purpose hardware including haptic interfaces, which provide tactile and force feedback sensations to the user. In *Figure 2*, two such devices are being used – one to simulate an ultrasound transducer placed against a virtual patient, and the second to simulate a needle puncture.[13] For a high fidelity simulation, the visualization and the force models must be computed in real time. This is a challenging process involving collision detection, soft tissue deformation and other compute intensive tasks.

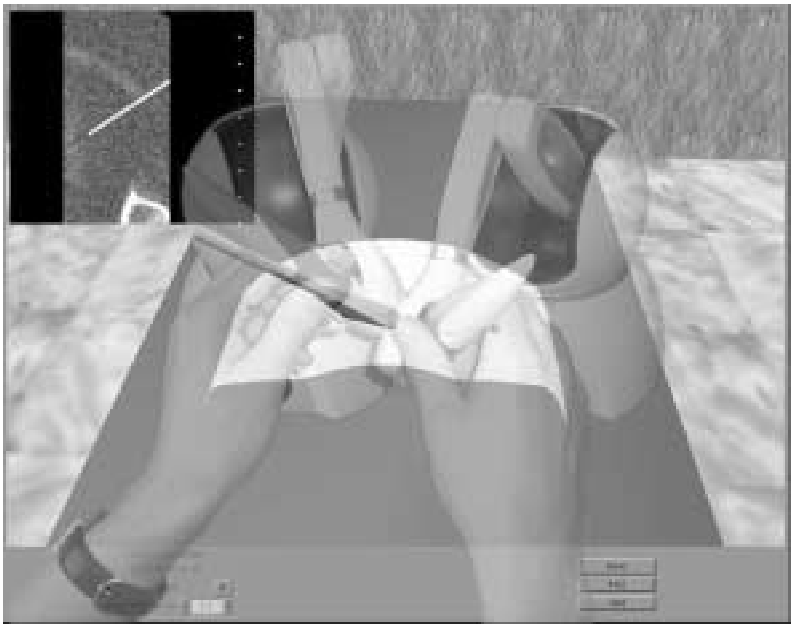

Figure 2. The Bangor Image Guided Needle Puncture Simulator (BIGNePSi).

There have also been effective examples of low fidelity simulators based on Web technologies. Our previous work has included simulators for lumbar puncture; ventricular catheterization; and Verres needle puncture and trocar placement, preparatory tasks for laparoscopic surgery (*Figure 3*).[14,15]

Despite being constrained to run within a web browser, these examples of cybermedicine tools still support extensive interaction: the torso can be deformed as if you were pressing your hand onto the skin; a needle can be positioned, orientated and inserted through the torso; insufflation can be simulated during which the torso will expand as if it if being pumped full of gas; and other surgical tools such as trocars can be selected and inserted into the torso. All of the models in these examples are rendered using the Virtual Reality Modeling language (VRML), with the interaction and user interface being controlled by Java applets. With the lumbar puncture example, validation studies with medical students at St Mary's Hospital, London have shown that using this simulator does improve the training of students in performing this procedure.[16]

Planning and Diagnosis

3D medical visualization has been available for many years in the radiology department as an aid to planning and diagnosis. In our final example of a cybermedicine tool, we delivered this functionality to a surgeon in the operating theatre allowing him/her to interrogate patient specific volume data.[17] *Figure 4*

Figure 3. 3D Web-based Training Tools for Lumbar Puncture (left) and Insertion of Verres Neeedle and Trocars for Laparoscopy (right). Courtesy of Manchester Visualization Centre.

Figure 4. The Op3D System. Real time Volume Rendered images of the patient are delivered to the Operating Room.

shows the Op3D system in use at the Manchester Royal Infirmary. The CT data set of the patient was too large to be rendered in real time on a PC that could be located in the operating theatre. A server located about one mile away was powerful enough to perform this task, however. The volume rendering was therefore carried out remotely with the images being sent across the computer network to the operating theatre. The surgeon uses the joystick to rotate the volume data set and to manipulate clipping planes as if the application is running locally. Collaborative visualization was also supported. If necessary, a second person could access the same visualization at the same time and consult with the surgeon in the operating theatre.

This research demonstrated that the success rate of hepato-pancreatic surgical resections was improved by replacing the light box in the operating room with an interactive 3D representation of the medical data.

Another growing use for volume rendering of high resolution medical scan data is for virtual autopsies,[18] used as a complement to conventional autopsies and even as a potential replacement for some cases. A virtual autopsy enables systematic but non-intrusive examinations of the whole body, which would be more difficult and time consuming otherwise. Not only prior to a physical autopsy, but one can also carry out the virtual autopsy later to answer any new questions raised during the physical autopsy. In order to make the virtual autopsy practical, however, we have to overcome various technical challenges:[19] fast computing and visualization of high resolution whole body scans, seamless visual exploration and zooming, interactive and intuitive adjustment of optical encoding of the scan data, etc. Unlike the previous example, we would also prefer the application to run on commodity desktop systems and graphics hardware. Finding solutions to these problems so that virtual autopsies become readily and widely available for practical uses is one of the current research themes at Bangor and elsewhere.

STANDARDS

The examples from the previous section all rely on medical scan data for direct volume rendering and/or the generation of anatomical models. Access to medical images is facilitated by the DICOM (Digital Imaging and Communications in Medicine) standard.[20] DICOM ensures interoperability between all medical imaging devices and electronic health record systems. The fundamental components of DICOM are information objects (that define the core contents of medical imaging) and the service classes (that define what to do with those contents). This combination is called a service-object pair class, or SOP class.

More than twenty active DICOM working groups are addressing any changes and additions needed, for example, a joint DICOM/ISO working group recently produced a new standard enabling Web Access to DICOM Objects. This development is helpful for the future of cybermedicine tools. Also relevant are the activities of DICOM Working Group 17, which aims to *'extend the DICOM Standard with respect to 3D and other multi-dimensional data sets that relate to real world domains of space, time, and physical properties, both measured or derived'*. The current focus here is defining multi-dimensional SOP classes for registration, storage and presentation.

Another important standard for cybermedicine tools is X3D, an ISO-ratified format for quick and easy sharing of real-time 3D models, visual effects, behavioural modeling, and interaction.[21] X3D is the successor of VRML, and provides an XML encoding so that interactive 3D and multimedia content can be read or written using standard XML tools and can be integrated seamlessly into any XML enabled application or web service. Developers can also exploit the X3D component architecture and XML schema to add vertical market specific capabilities. Of note, a medical working group is currently building an extension to X3D, called medX3D, which includes contributions from the Bangor research team. Our goal is to extend X3D to enable volumetric rendering, segmentation and registration of multimodal medical images. This work is currently being progressed so that it is compatible with DICOM. The medX3D standard will further support bringing cybermedicine tools such as 3D anatomical reconstructions of actual patient data to the common desktop or handheld computer.

CONCLUSIONS

Technology developments, particularly the ever improving cost effectiveness of 3D computer graphics will be a significant factor in the future development of cybermedicine. Through our research projects we have demonstrated:

- Use of cybermedicine tools for anatomy training does enhance the education process, particularly when used as part of an integrated training package that also includes video clips, text book descriptions, and self assessment tools.
- An important issue with the deployment of 3D technology is that of scalability (of the visualization, of the models, of the haptic feedback, etc.) to handle different platforms and different data rates. Decisions often have to be made about gaining extra performance at the expense of the overall quality of the simulation.
- To date, web-based solutions offer a low fidelity simulation for procedural training tools but nevertheless have a role to play in providing added value to the training process.
- There is a trend for advanced functionality (soft tissue modelling, use of haptics, etc.) to move from bespoke high performance systems down to the web browser, increasing the accessibility of cybermedicine tools.

The fact that a web-based tool can be available at any time and from any PC connected to the internet, means that the demand for advanced cybermedicine applications will continue to grow from both patients and physicians alike. Recent standards activities are further reinforcing this trend. The growing cybermedicine community, both technologists and domain experts, will need to collaborate closely to effectively deliver the potential benefits.

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